

Natural sciences for schoolteachers

LESSON 3:

Energy transfer

Contents

1. Work and energy.
2. Energy forms and sources.
3. Heat and temperature.
4. Energy conservation, transformation, and degradation.

Work and energy

Work

In physics, whenever a **force** is applied to an object, causing a **displacement** of the object in the direction of the force, **work** is done by the force.

Mathematically, we can express work as:

$$W = F \cdot \Delta x$$

Therefore,

- 1) No work is done without a displacement.**
- 2) The displacement must occur in the direction of the force** (i.e., a vertical force does not do work on a horizontally displaced object).

Work and energy

Work

Force is measured in newtons (N) and displacement in meters (m).

What are the units of work?

$$W = F \cdot \Delta x$$

$$[W] = N \cdot m = kg \cdot m^2 / s^2 = J$$

The unit of work in the International System of Units is the **joule**, which is the work done to an object when a force of 1 N acts on that object in the direction of its motion through a distance of 1 m.

Work and energy

Power

In everyday life, we are not so interested in the amount of work done as in how effectively it is done (or how quickly it is done).

In physics, **power** is the rate at which work is done.

Mathematically, we can express power as:

$$P = \frac{W}{\Delta t}$$

Work and energy

Power

Work is measured in joules (J) and time in seconds (s).

What are the units of power?

$$P = \frac{W}{\Delta t}$$

$$[P] = \frac{J}{s} = \frac{N \cdot m}{s} = \frac{kg \cdot m^2 / s^2}{s} = kg \cdot m^2 / s^3 = W$$

The unit of power in the International System of Units is the **watt**, which is equal to a work of 1 J per second.

Work and energy

Power

Electrical appliance	Power (W)
Fridge	250 – 350
Microwave	900 – 1 500
Washing machine	1 500 – 2 200
Dishwasher	1 500 – 2 200
Oven	1 200 – 2 200
Glass-ceramic cooktop	900 – 2 000
TV	150 – 400
Air conditioner	900 – 2 000
Electric heater	1 000 – 2 500

Work and energy

Energy

In physics, **energy** is the **capacity** of objects **for causing changes** in themselves or other objects.

Therefore, **work** is the ***transfer of energy from one system to the outside or vice versa.***

$$W = \Delta E$$

If work is done by the system, its energy will decrease ($W < 0$). If work is done on the system, its energy will increase ($W > 0$).

The unit of energy in the International System of Units is the **joule**.

Work and energy

Energy

A commonly used unit of energy is the **kilowatt per hour (kWh)**, which is the amount of energy delivered by a machine with a power of 1 kW for one hour.

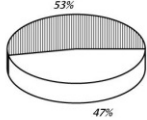
$$1 \text{ kWh} = 1\,000 \text{ W} \times 3\,600 \text{ s} = 3\,600\,000 \text{ W}\cdot\text{s} = 3\,600\,000 \text{ J}$$

IN DE ÚLTIMO RECURSO, S.A.U. – Plaza Euskadi 5, 48009 Bilbao; inscrita en el Registro Mercantil de Bizkaia al Tomo 5015, Folio 1°

2		FACTURACIÓN	
		EUROS	
4	ENERGÍA		
	Potencia contratada	4,6 kW x 29 días x 0,059817 €/kW día	7,98
	Energía consumida	437,11 kWh x 0,142138 €/kWh	62,13
		223,89 kWh x 0,142208 €/kWh	31,84
5		-539 kWh x 0,142138 €/kWh	-76,61
	Impuesto sobre electricidad	4,864% s/25,34 x 1,05113	1,30
	TOTAL ENERGÍA		26,64
6	SERVICIOS Y OTROS CONCEPTOS		
	Alquiler equipos de medida	29 días x 0,027541 €/día	0,80
	TOTAL SERVICIOS Y OTROS CONCEPTOS		0,80
	Importe total		27,44
	IVA	18% s/27,44	4,94
	TOTAL IMPORTE FACTURA		32,38

¿Cuál es el destino de lo que paga en su factura?

De los 32,38 € de su factura, 17,08 € están destinados al pago de impuestos y otros recargos establecidos por la normativa en vigor, ajenos al suministro. Los 15,30 € restantes están destinados al pago de la producción y suministro de la energía así como a la retribución de las redes eléctricas.



- Impuestos, recargos y otros conceptos
- Costes suministro eléctrico

Costes suministro eléctrico	
Producción y suministro de la energía	9,72€
Retribución de las redes eléctricas	5,58€
	15,30€
Resto de costes	
Recargos por normativa vigente	10,84€
Impuestos (IE+IVA)	6,24€
	17,08€
Total	32,38€

Para realizar los cálculos se ha utilizado el valor del coste de la energía fijado en la Resolución de 25 de abril de 2012, de la DGPEM (BOE 26/04/2012)

Work and energy

Energy

Living things need food to obtain energy and transform it to perform their daily activities.

In **nutrition**, the unit of energy commonly used to express the amount of energy provided by food is the **calorie**.

$$1 \text{ cal} = 4.1868 \text{ J}$$

Example:

A person needs about 2 000 kcal daily, i.e., 8 373.6 kJ.

This energy is equal to the energy needed to light a bulb with a power of 100 W for 23 h, 15 min and 36 s.

Work and energy

Energy

Activity	Work (kcal) in 1 hour	Power (W)
Sitting	15	17
Walking	200	350
Running	800 – 1 000	930 – 1 200
Dancing	200 – 400	230 – 460
Playing tennis	400 – 500	460 – 580
Swimming	300 – 900	350 – 1 050

Work and energy

Energy

Food	Nutritional values (kcal) per 100g
White bread	258
Lettuce	14
Lentils	314
Egg	100
Whole cow's milk	65
Cod	83
Chicken	112
Pork chop	327
Orange	44
Almonds	620
Beer	45
Chocolate	518

Energy forms and sources

Energy forms

Energy can manifest itself in different ways, and, depending on the process, it is called:

- 1) mechanical energy
- 2) thermal energy
- 3) electric energy
- 4) radiant energy
- 5) chemical energy
- 6) nuclear energy

Energy forms and sources

Energy forms: mechanical energy

Mechanical energy is the energy associated with the motion and position of an object. It can be of two types:

- **Kinetic energy** (E_k), which is the energy associated with the motion of an object.
- **Potential energy** (E_p), which is the energy associated with a system's configuration.

$$E = E_k + E_p$$

Energy forms and sources

Energy forms: mechanical energy – kinetic energy

The **kinetic energy** (E_k) is the energy associated with the ***motion*** of an object.

Its value depends on the mass (m) and the speed (v) of the object.

$$E_k = \frac{1}{2} m \cdot v^2$$

Example:

The kinetic energy of the wind is used in wind turbines to generate electricity.



Energy forms and sources

Energy forms: mechanical energy – potential energy

The **potential energy** (E_p) is the energy associated with the *system's configuration*.

- The **gravitational potential energy** is the energy associated with the height above ground of an object.
- The **elastic potential energy** is the energy associated with the deformation of an object.

Energy forms and sources

Energy forms: mechanical energy – potential energy

The **gravitational potential energy** is the energy associated with the height above ground of an object.

Its value depends on the mass (m) of the object, gravity (g), and the height above ground (h) of the object.

$$E_p = m \cdot g \cdot h$$

Example:

Hydroelectric power plants use the gravitational potential energy that a mass of water has due to a difference in height.



Energy forms and sources

Energy forms: mechanical energy – potential energy

The **elastic potential energy** is the energy associated with the **deformation** of an object. Its value depends on the elasticity of the object (k) and how much it has been deformed (x).

$$E_p = \frac{1}{2}k \cdot x^2$$

Example:

When the string of a bow is drawn back, it bends the limbs of the bow, storing elastic potential energy. When the string is released, the potential energy in the bow limbs is transformed into the kinetic energy of the arrow as it takes flight.



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Energy forms and sources

Energy forms: thermal energy

Thermal energy is the total kinetic energy of a *system's constituent particles* (atoms, molecules, etc.), which are in constant *motion*.

The faster the particles move, the more kinetic energy they have.

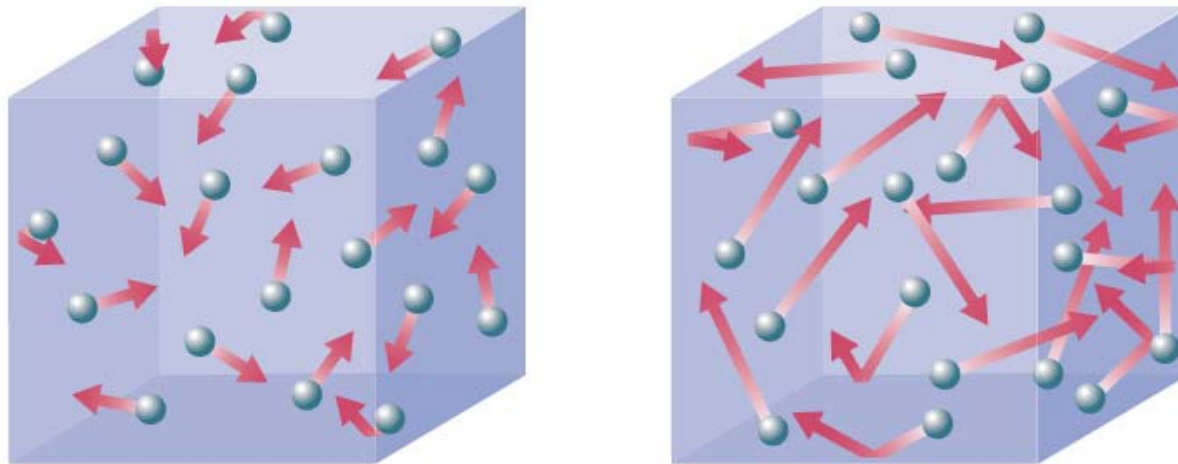


Image: Addison Wesley

Energy forms and sources

Energy forms: electric energy

Electric energy is the energy caused by the *motion* of *electrical charges* inside *conductors*.

It is used in everyday life, and through it, we can use a computer, illuminate our homes, keep food fresh in a fridge, etc.



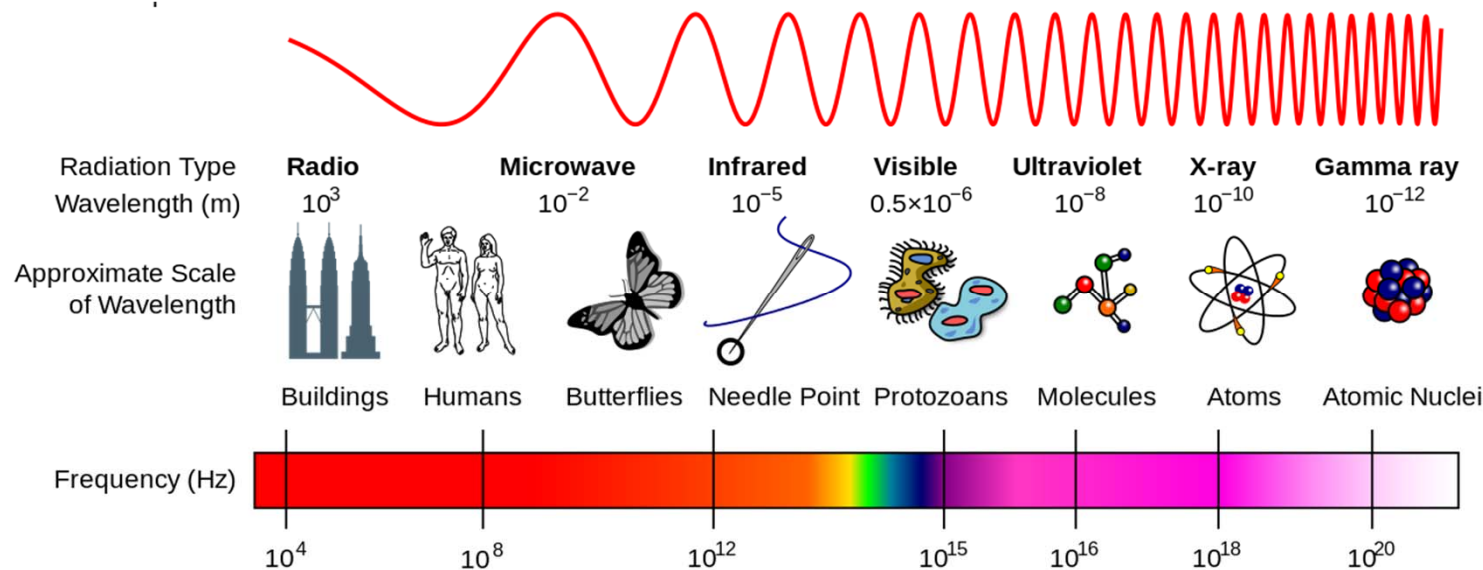
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Energy forms and sources

Energy forms: radiant energy

Radiant energy is the energy of *electromagnetic waves* such as visible light, radio waves, UV radiation, and IR radiation. These waves do not require the presence of a material medium to transport their energy from one location to another.

Example: The energy emitted by the Sun reaching Earth in the form of light and heat is radiant energy.



Energy forms and sources

Energy forms: chemical energy

Chemical energy is energy stored in the bonds of atoms and molecules of *chemical compounds* and released in *chemical reactions*.

Example: the combustion of butane



Energy forms and sources

Energy forms: nuclear energy

Nuclear energy is the energy that holds together the **nuclei** of atoms, and which is released in **nuclear reactions**. The nuclear reactions that release energy are:

- **nuclear fission**: the (heavy) nucleus of an atom splits into two or more smaller (lighter) nuclei.
- **nuclear fusion**: two or more atomic nuclei join to form a heavier nucleus.

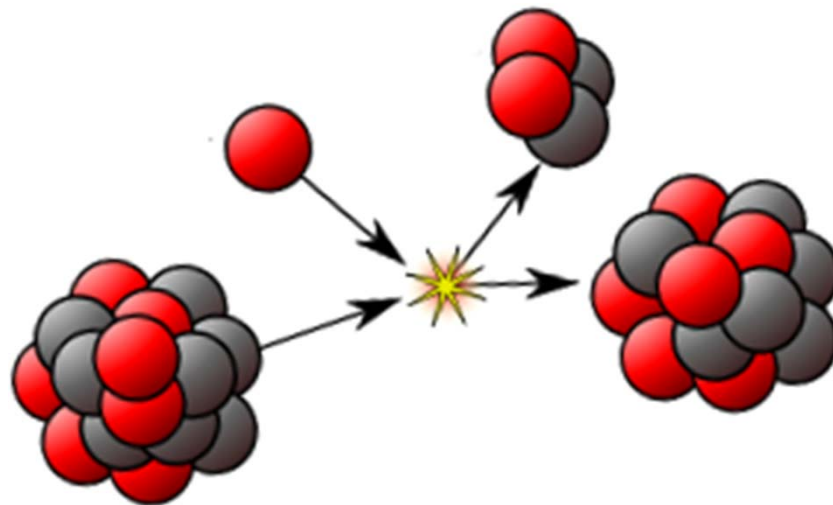


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Energy forms and sources

Energy sources

An **energy source** is any material or natural resource from which energy can be obtained, either for direct use or to transform it.

Energy sources are classified into:

- 1) **Renewable:** which can be used continuously, since they are replenished constantly (such as wind, sunlight, and tides).
- 2) **Non-renewable:** which once used take too long to renew themselves, or will never renew (fossil fuels and nuclear energy).

Energy forms and sources

Energy sources: renewables

- 1) **Wind power.** Energy obtained from *air flow* using *wind turbines*.
- 2) **Solar energy.** The electromagnetic radiation that reaches Earth from the *Sun*.
- 3) **Hydropower.** Energy obtained from falling or fast running *water* retained in reservoirs.
- 4) **Geothermal energy.** The heat generated and stored in the *Earth*.
- 5) **Biomass.** Energy obtained from *organic matter* either directly (combustion) or indirectly (biofuel).
- 6) **Tidal power.** Energy obtained from *tides* and *waves*.



Image: Leaflet
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Image: U.S. Air Force

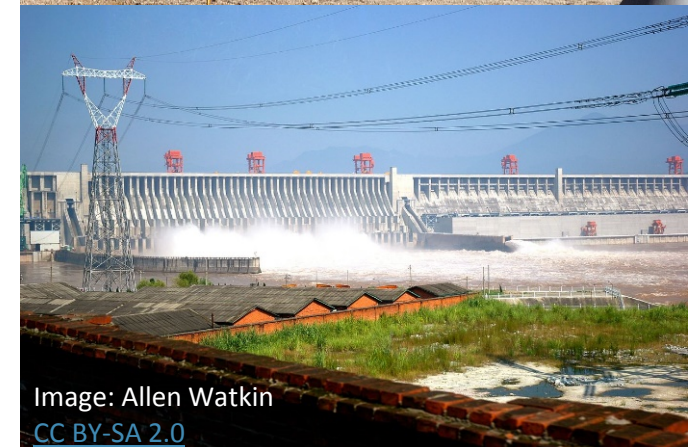


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Energy forms and sources

Energy sources: non-renewables

- 1) **Fossil fuels** (*petroleum*, *coal* and *natural gas*). Formed by the accumulation, millions of years ago, of large quantities of organic remains at the bottom of seas and lakes.
- 2) **Nuclear energy**. The energy that holds together the nuclei of atoms, and which is released in nuclear reactions (nuclear fission or fusion).



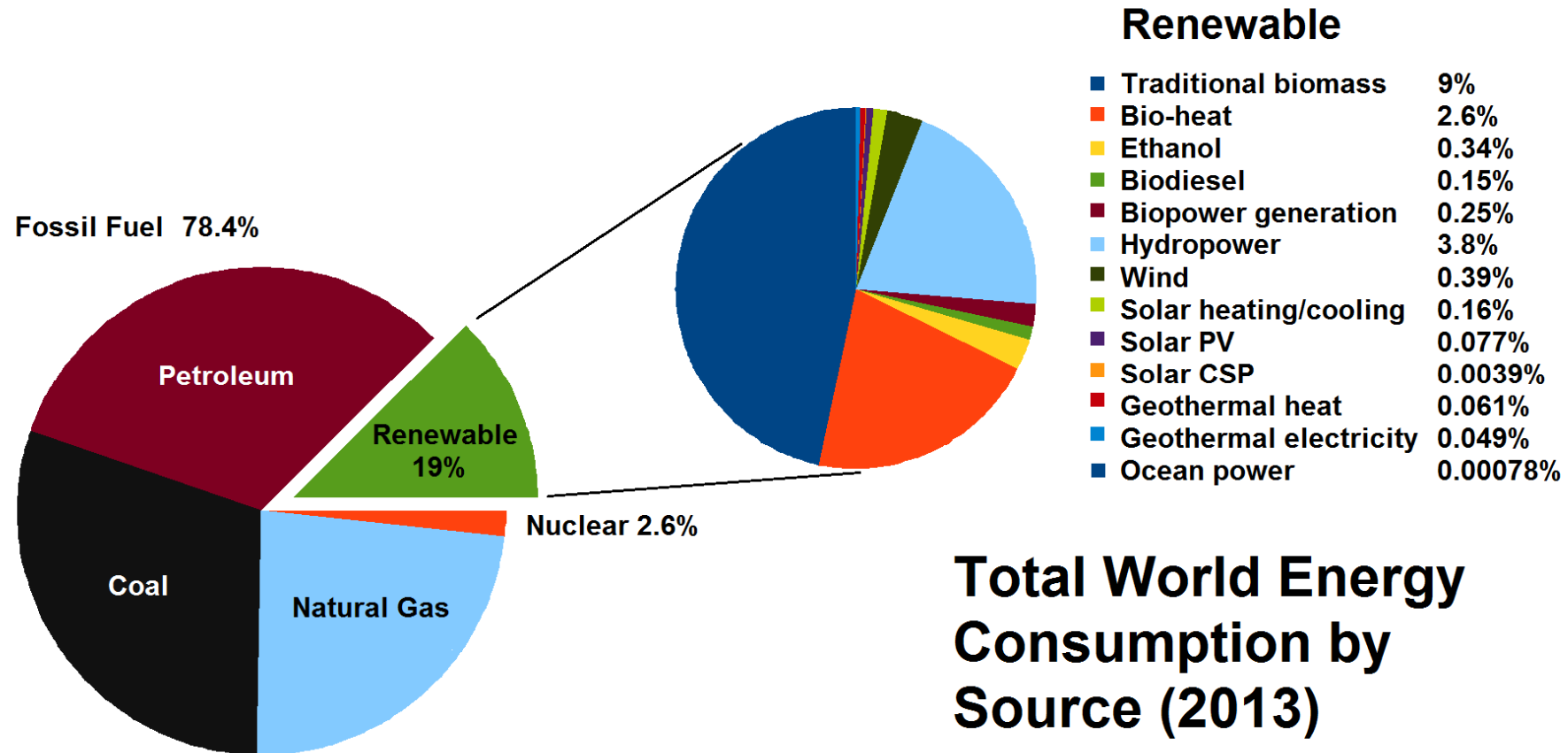
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Image: U.S. Department
of Energy

Energy forms and sources

Energy sources



REN21 Renewables 2014 Global Status Report

Heat and temperature

Temperature

We usually associate the concept of temperature with how 'hot' or 'cold' objects feel when touched.



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Heat and temperature

Temperature

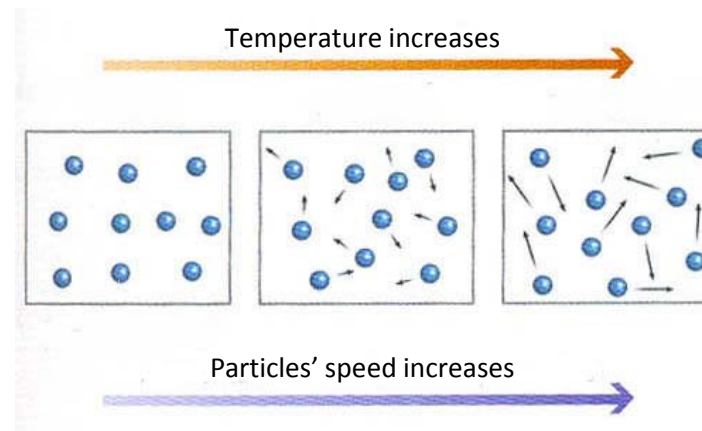
Our sense of touch provides a qualitative indication of the temperature - but is not very reliable.

Therefore, we need a reliable and reproducible method to determine how relatively 'hot' or 'cold' objects are, and which is exclusively related to the temperature of the object.

Heat and temperature

Temperature

The **temperature** of a system is a measure related to the average kinetic energy of its particles ...



... but this energy is very difficult to calculate.

Heat and temperature

Temperature

Fortunately, some systems have **observable properties** that vary with **temperature**:

- volume of a liquid
- length of a solid
- electrical resistance of a conductor
- thermal radiation emitted

Thermometers are instruments that use some of these physical properties for measuring the temperature of an object.

Heat and temperature

Temperature

Example:

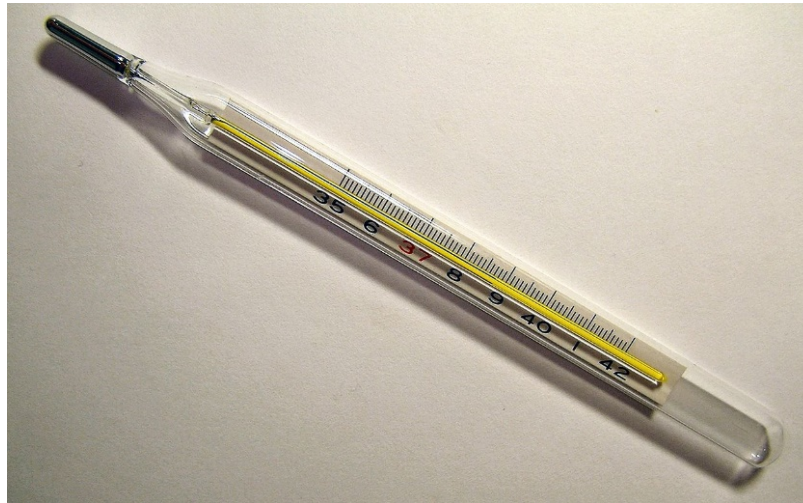


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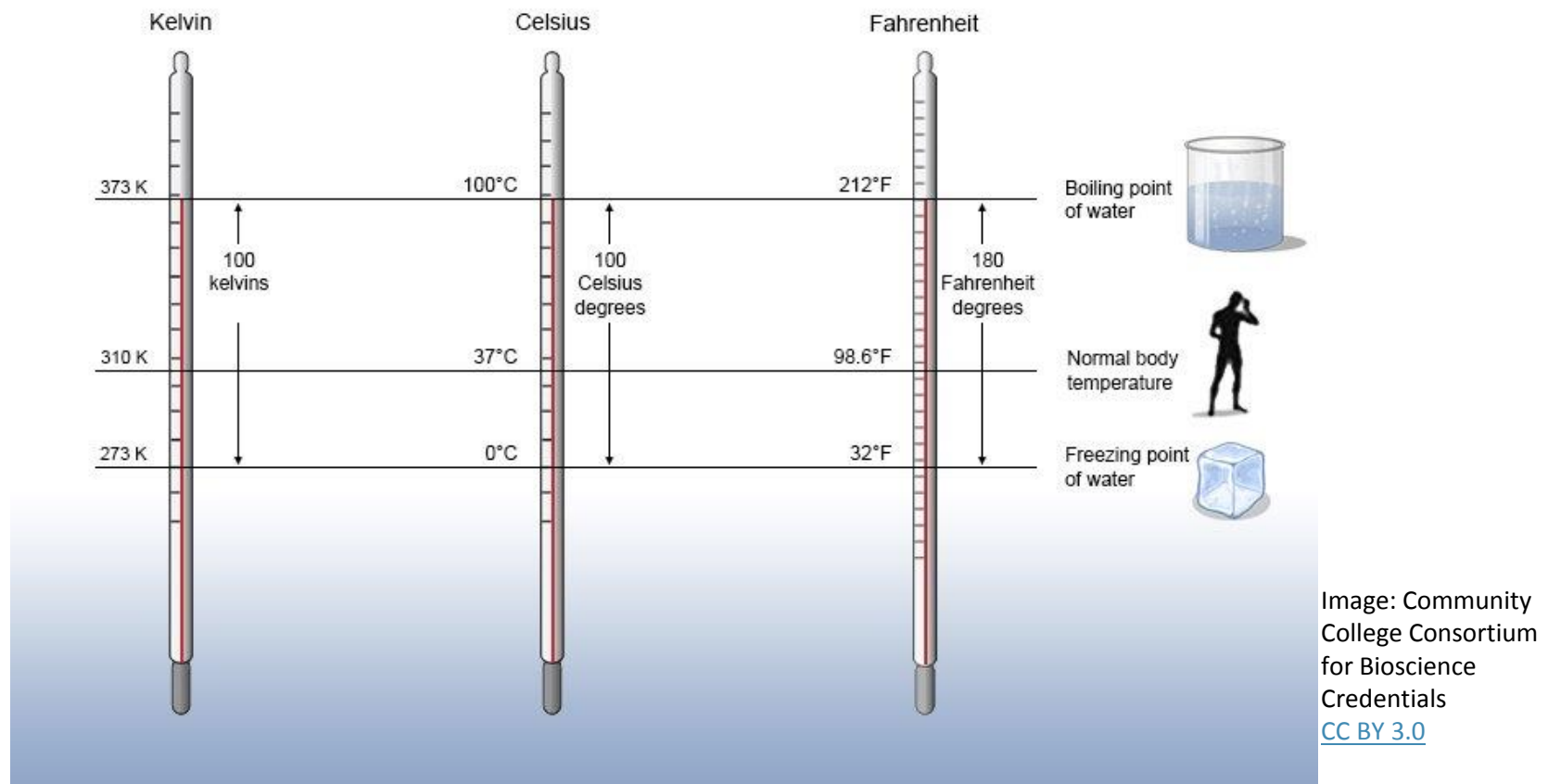


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Heat and temperature

Temperature scales

The temperature unit in the International System is the **Kelvin**, although the use of other temperature scales (***Celsius*** or ***Fahrenheit***) is common for everyday applications.



Heat and temperature

Temperature scales

- In **Celsius** (°C), 0°C is defined as the freezing point of water and 100°C is defined as the boiling point of water. This scale is divided into 100 equal degrees between those two points.
- In **Fahrenheit** (°F), 0°F is defined as the temperature of a solution of brine (solution of salt in water) in ice. Further limits were established as the melting point of ice (32°F) and an estimate of the average human body temperature (96°F). This scale is divided into 180 equal degrees between the freezing and boiling points of water.

$$F = 1.8 \cdot C + 32$$

- The **Kelvin** (K) scale is based on a single point (0 K, absolute zero), which corresponds to the temperature at which the molecules and atoms of a system have the minimum possible thermal energy. From there, the scale increases by equal degrees that are the same size as Celsius degrees.

$$K = C + 273.15$$

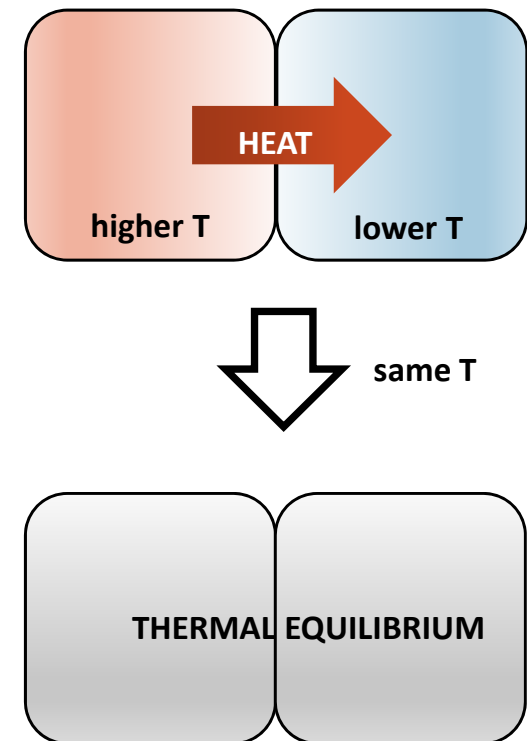
Heat and temperature

Heat

Heat is the **energy** in transit from one object to another due to a difference of temperature.

This transfer of energy always happens from a high temperature object to a lower temperature object, until both reach the same temperature (**thermal equilibrium**).

The unit of heat in the International System of Units is the **joule**.



Heat and temperature

Heat transfer

Heat can be transferred from place to place by:

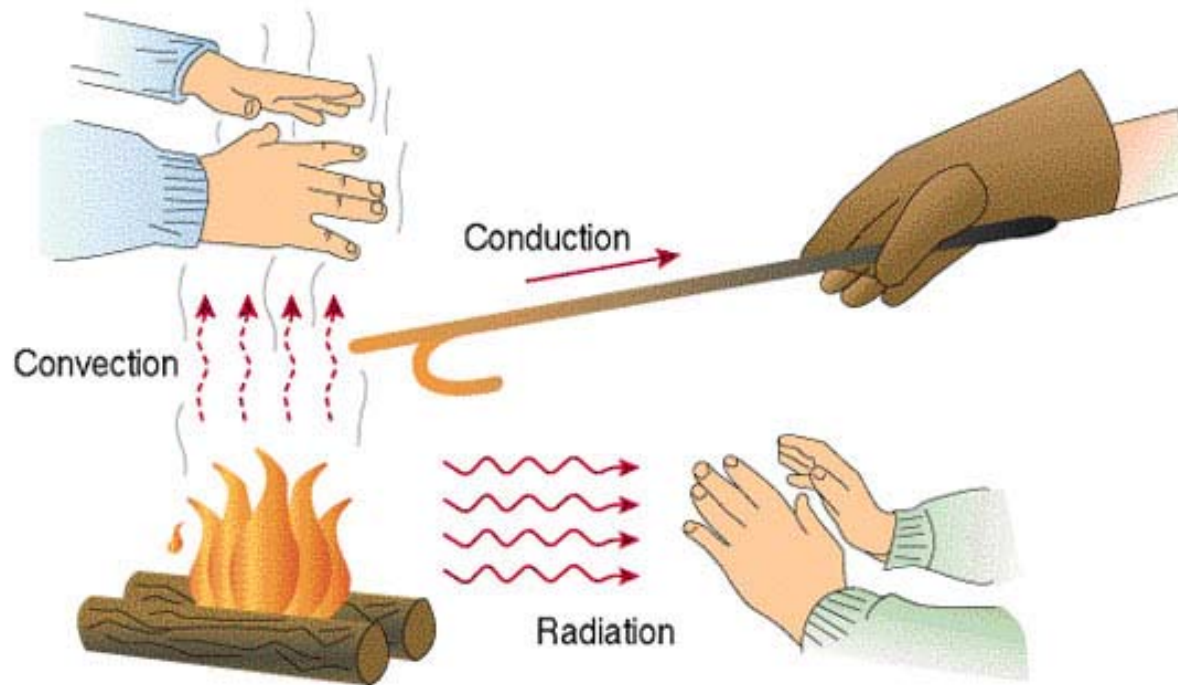


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Heat and temperature

Heat transfer

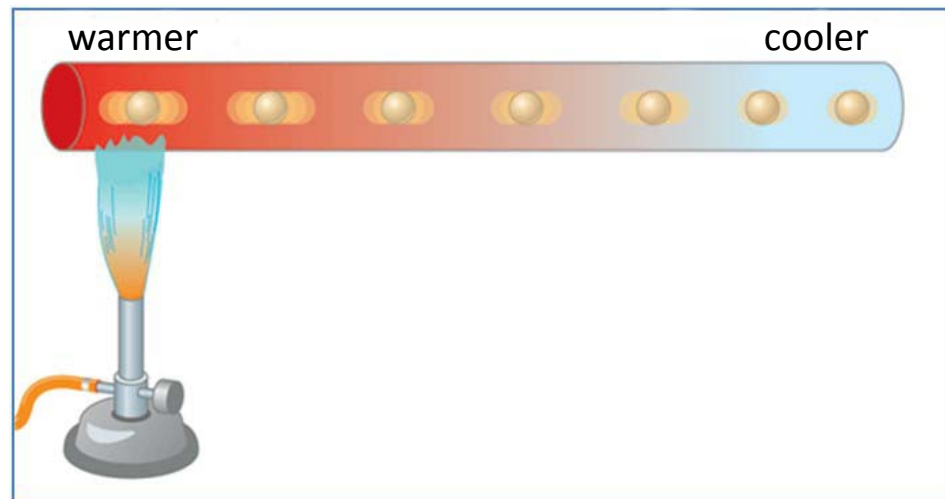
Heat can be transferred from place to place by:

1. **Conduction**, which is heat transfer by means of collisions of particles (atoms, molecules, etc.) within an object or between contiguous objects.
2. **Convection**, which is heat transfer by means of the movement of fluids (liquids or gases).
3. **Radiation**, which is heat transfer by means of electromagnetic waves, and does not involve the movement or the interaction of matter.

Heat and temperature

Heat transfer: conduction

If one end of a metal rod is at a higher temperature, as one particle vibrates it causes the next in line to vibrate also. This process repeats, particle after particle, allowing energy to be transferred down the rod towards the colder end.



In conduction, the particles in the solid do not move and only vibrate.

Heat and temperature

Heat transfer: convection

Fluids (liquids and gases) usually expand when they are heated. The fluid in hot areas is less dense than the fluid in cold areas, so it rises into the cold areas. The denser cold liquid falls into the warm areas. In this way, **convection currents** that transfer heat from place to place are set up.

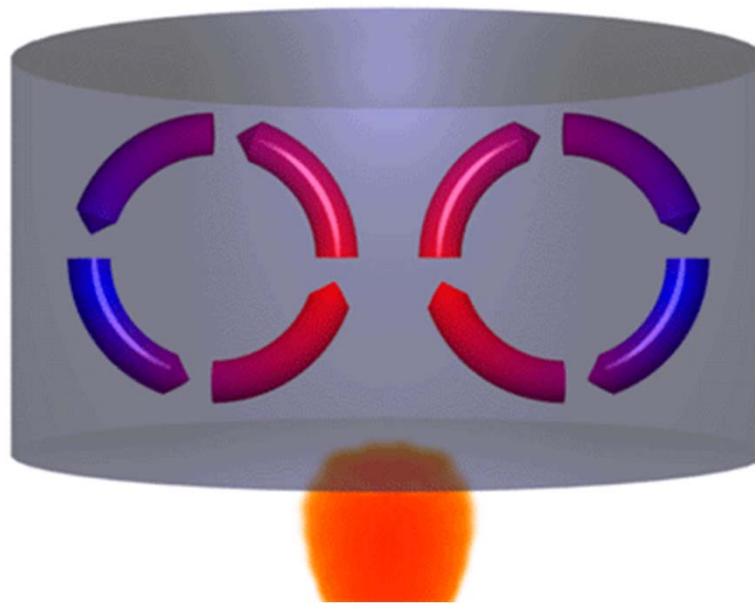


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Heat and temperature

Heat transfer: radiation

All objects radiate energy in the form of *electromagnetic waves*. The hotter the object, the more it radiates.

Radiation does not require the presence of matter, and it is the only means of an object transferring energy in a *vacuum*.

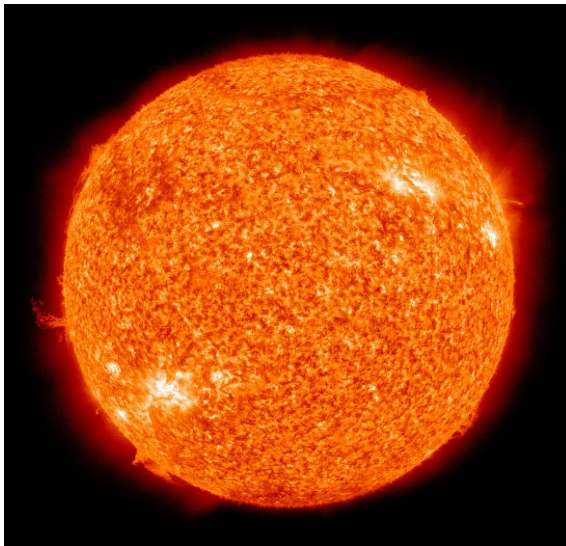


Image: NASA/SDO (AIA)



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Energy conservation, transformation, and degradation

Energy conservation

We can change the position of an object (**potential energy**) or its speed (**kinetic energy**) by doing work on it.

In general, by doing work on an object, we can simultaneously modify its position and speed, and thus:

$$W = \Delta E = \Delta E_k + \Delta E_p$$

where the total energy of the object is given by:

$$E = E_k + E_p$$

Energy conservation, transformation, and degradation

Energy conservation

The **law of conservation of energy** states that:

'Energy is neither created nor destroyed, only transformed.'

In these transformations, the total energy remains constant, i.e., the total energy is the same before and after each transformation.

$$\Delta E = 0$$

Energy conservation, transformation, and degradation

Energy conservation

“Energy is neither created nor destroyed, only transformed.”

In the case of mechanical energy, it can be concluded that, in the absence of friction and without any external work, the sum of the kinetic and potential energies remains constant.

$$\Delta E = \Delta E_k + \Delta E_p = 0 \rightarrow \Delta E_k = -\Delta E_p$$

$$E = E_k + E_p = \text{constant}$$

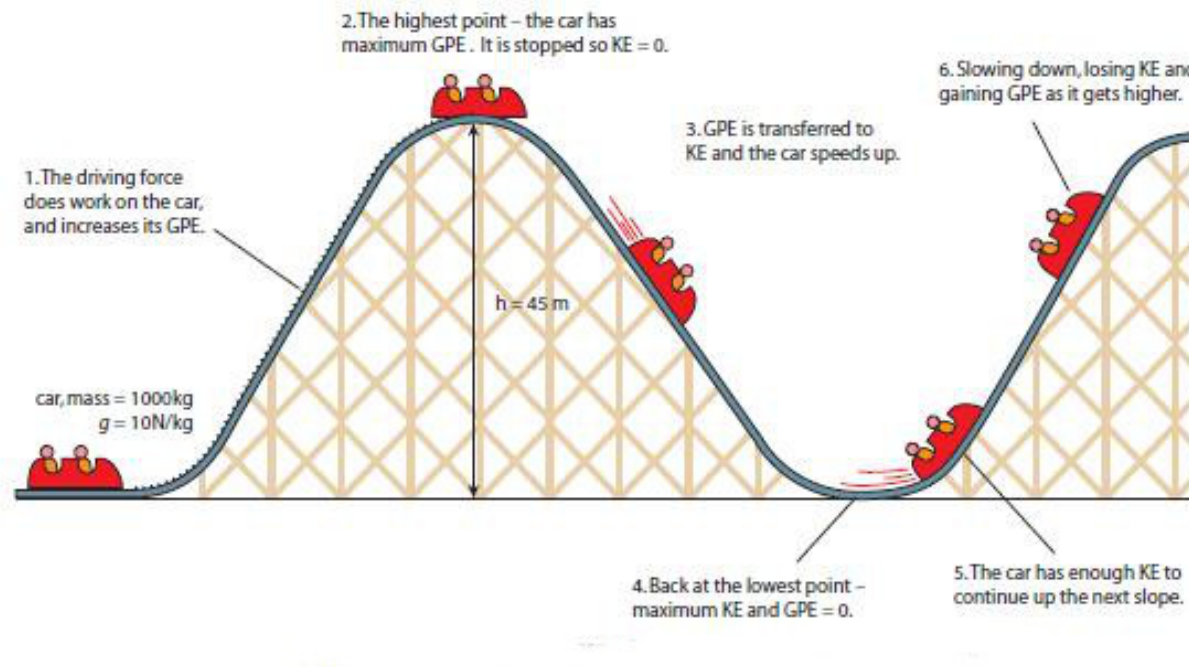
That is, the kinetic energy can be converted into potential energy and vice versa.

Energy conservation, transformation, and degradation

Energy conservation

'Energy is neither created nor destroyed, only transformed.'

Example:



<https://youtu.be/rKLtuc-N7EE>

Energy conservation, transformation, and degradation

Energy conservation

'Energy is neither created nor destroyed, only transformed.'

Example:



<https://youtu.be/xXXF2C-vrQE>

Energy conservation, transformation, and degradation

Energy conservation

'Energy is neither created nor destroyed, only transformed.'

Example:

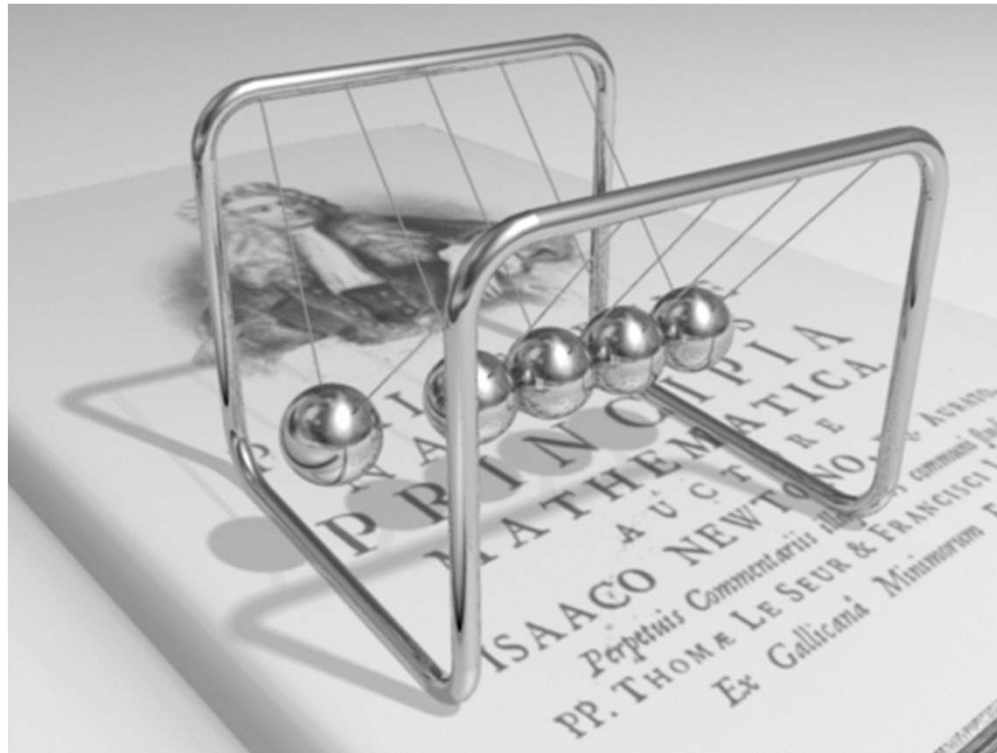


Image: Dominique Toussaint
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http://youtu.be/8p1ZJ_WBRkU

Energy conservation, transformation, and degradation

Energy transformation

Energy is constantly changing from one form to another. Energy always goes from a 'more useful' to a 'less useful' form (referring to the ability to do work).

Example:

*When we fill the fuel tank of a car, we are introducing a certain amount of **chemical energy**. The combustion of the gasoline inside the engine converts the chemical energy into **heat**, which causes the expansion of the gases from the combustion, and thus doing **mechanical work**. The motor gears transmit the mechanical energy to the wheels, which move the car. A portion of all the generated energy is converted into **heat** in the engine and the tires. A part of that energy is also transformed into **noise**.*

Energy conservation, transformation and degradation

Energy degradation

Energy is constantly changing from one form to another, and after each transformation, **energy** loses quality, becomes less useful, and **degrades**.

In every transformation, part of the energy is transformed in **heat**. Any form of energy can be completely transformed in heat, but heat cannot completely be transformed in any other form of energy. Therefore, it is said that ***heat is a degraded form of energy***.

Examples:

Electric energy is transformed into heat in an incandescent bulb.

Chemical energy is transformed into heat during combustion.

Mechanical energy is transformed into heat by friction.

Energy conservation, transformation and degradation

Energy degradation

Therefore, the **efficiency** of a device can be defined (in %) as the ratio of the useful energy transferred and the total energy supplied in any transformation:

$$\text{Efficiency} = 100 \times \frac{\text{Useful energy}}{\text{Total energy}}$$

Example:

In an incandescent bulb, the efficiency is 5%. This means that only 5% of the electric energy consumed is used to provide light. The rest is lost as heat.

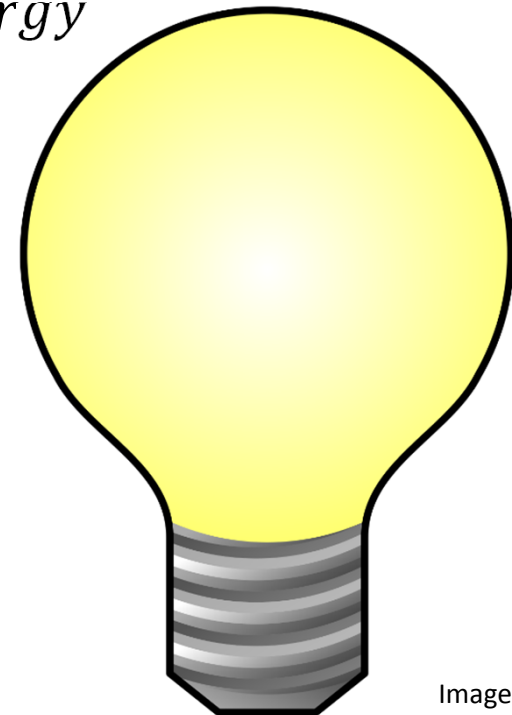


Image: Elembis